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Method and Device for Stabilizing a Car-Trailer Combination

The present invention relates to a method and a device for stabilizing a car-trailer combination, including a towing vehicle and a trailer moved by the towing vehicle, wherein the towing vehicle is monitored in terms of rolling motions and measures that stabilize driving are taken upon the detection of an actual or expected unstable driving performance of the towing vehicle or the car-trailer combination.

The method at issue aims at detecting and controlling the instabilities of car-trailer combinations (motor vehicle with trailer), especially of combinations consisting of a passenger car and any trailers desired, in particular caravans, before driving conditions are encountered which the driver can no longer master. These unstable conditions involve the rolling motions known with car-trailer combinations and the anti-phase building-up process between the towing vehicle and the trailer as well as imminent roll-over conditions at too high transverse accelerations in the event of obstacle avoidance maneuvers, lane changes, side wind, road irregularities or hasty steering maneuver requests by the driver.

Depending on the driving speed, the oscillations can decay, remain constant, or increase (undamped oscillation). When the oscillations remain constant, the car-trailer combination has reached the critical velocity. Above this speed threshold a car-trailer combination is unstable, below said threshold it is stable, that means, possible oscillations die out.

possibility of obtaining such variations of transverse quantities is to drive over rough roadways, in particular wavy road sections, especially bumps on alternating sides.

An object of the invention is to provide a method and a device permitting the reliable detection of unstable driving performance.

According to the invention, this object is achieved in that the yaw velocity is detected and the measures that stabilize driving are controlled in dependence on a differential value that is produced from the detected yaw velocity and a model-based yaw velocity and evaluated according to criteria indicative of an unstable driving performance.

Advantageously, the method allows reliably detecting snaking car-trailer combinations, in particular passenger car/trailer combinations. In this method, a differential value $\Delta\dot{\psi}$ is generated from the measured yaw rate and the model-based reference yaw rate, which value is representative of the deviation of the vehicle from the track predetermined by the steering wheel position. Because this differential value represents only the deviation from the desired track, monitoring the differential value ensures the judgment of oscillations independently of a curved track passed e.g. due to a steering angle. Preferably, the differential value is filtered in a low-pass filter in order to cut off signal peaks triggered by the detection of coefficients of friction. Spurious detections and, thus, faulty control activations are avoided in addition. The method and the device favorably require only a sensor system provided in an ESP driving stability control.

In this arrangement, an actuating signal for an electric motor of a hydraulic pump producing a braking pressure and, hence, actuating the wheel brake of the towing vehicle or the trailer is generated by way of the data measured by a yaw rate sensor, derived in an ESP driving dynamics control operation and logically combined with the ESP control strategy. In this data the data of a motor vehicle can be included. It is possible alternatively or additionally to drive an actuator of an overriding steering system. By applying equal or different braking pressure to one wheel of preferably the towing vehicle or to all wheels of the towing vehicle corresponding to an ESP control strategy, it is possible to correct the instabilities of the car-trailer combination detected by sensors and to reduce the possibly existing excessive transverse dynamics of the car-trailer combination by reducing the vehicle speed and/or the lateral forces at one wheel by means of increased braking pressure and/or the increase in the longitudinal forces.

It is favorable that the frequency and the amplitude of each half wave of the differential value is determined, compared to stored values, and the rolling motion of the car-trailer combination is evaluated in dependence on the result of the comparison.

Advantageously, the oscillation frequency of the car-trailer combination is achieved in that the frequency is determined from the zero crossings and the time between two zero crossings of the yaw velocity.

The condition for detecting a snaking, unstable car-trailer combination is favorably satisfied by the following steps: counting the number of the half waves of the differential

value where the amplitude of each half wave reaches or exceeds a threshold value, counting each positive and negative half wave of the determined frequency when each positive and negative half wave lies within a band defined by a top and a bottom threshold value, and comparing the value of the half waves counted with a threshold value representative of a number of half waves, and measures that stabilize driving are initiated when the threshold value is reached or exceeded. It is favorably arranged for that the conditions are continuously satisfied and the half waves are serially counted in order that the threshold value representative of a number of half waves is reached or exceeded, respectively. The threshold value representative of a number of half waves can favorably be determined in dependence on the frequency, and at low frequencies, the threshold value is reached or exceeded with a smaller number of half waves than is the case at a high frequency.

Further, it is advantageous that the threshold value of each half wave representative of the amplitude is determined at least in dependence on quantities that represent the velocity of the towing vehicle or the car-trailer combination or the trailer. It is arranged for that with quantities describing a high speed, the threshold value is reached or exceeded at lower amplitudes than is the case with quantities describing a low speed.

To avoid constant activation and deactivation of the controller (ESP driving stability controller), only a consecutive number of half waves of the yaw velocity are counted where the amplitude of each half wave reaches or exceeds an entry threshold value, and the measures that stabilize driving are terminated when values reach or fall

below only one exit threshold value ranging below the entry threshold value.

In a preferred embodiment of the invention, the data is produced from the variation of the differential value. The model-based yaw velocity is calculated in a vehicle model that is a component of an ESP driving stability control in a favorable manner. In the vehicle model, in particular the single-track model, the model yaw rate is generally produced from the steering angle, the transverse acceleration and the vehicle speed (vehicle reference speed).

Surprisingly, it has shown that at rapid changes of the steering angle, i.e. at high steering angle speeds, deviations in the vehicle model are generated which cause a signal variation that is confusable with the monitored signal variation when the car-trailer combination is snaking. It is assumed that these deviations are due to the reaction times of the signal generation, on the one hand, and the retarded vehicle reaction, on the other hand. To avoid these faulty detections, provisions are made to ensure that the differential value is weighted with a value, in particular a factor, which is produced in dependence on the steering angle velocity or the steering angle acceleration or preferably the model deviation or deviation of the reference yaw rate, respectively. The reason is that it has been found out that the model yaw rate deviation or the model yaw rate speed, respectively, is most appropriate for filtering the differential value because the vehicle speed vRef and the steering angle velocity $\dot{\delta}$ go into said value.

In a particularly favorable embodiment of the method, the transverse acceleration is detected and the variation of the

transverse acceleration is evaluated according to criteria which allow checking the plausibility of the data obtained from the variation of the differential value and being assessed according to criteria indicative of an unstable driving performance.

Plausibility is checked by way of finding out the maximum and minimum values of the transverse acceleration and their temporal distances, by determining the frequency and comparing it with the frequency of the differential value.

Plausibility is additionally checked and the method is terminated or the measures that stabilize driving are discontinued when at least one of the following conditions is satisfied:

The frequency of a transverse signal or a transverse quantity, such as the transverse acceleration and/or the differential value reaches or exceeds or, respectively, falls below a top or a bottom threshold value;
The frequency of the transverse signal changes in relation to the frequency of the differential value towards a top or a bottom limit value;
The absolute value of the average value of the transverse signal exceeds a threshold value;
The amplitude of the transverse signal decreases with a high gradient;
The difference between the maximum and minimum values of the transverse signal lies in a narrow band.

As the phase shift is small in snaking car-trailer combinations, it is favorably arranged for that the phase shift between the transverse acceleration and the differential

value is determined and evaluated according to criteria that permit determining driving situations.

It is favorable that the measures that stabilize driving are discontinued or the method is terminated, respectively, when a threshold value indicative of a great phase shift is exceeded.

Further, an object of the invention relates to a device for stabilizing a car-trailer combination, including an ESP driving stability control, with a yaw rate sensor for sensing the yaw velocity and a vehicle model for producing a reference yaw velocity,
with a determining unit determining a differential value from the yaw velocity and the reference yaw velocity,
with a control unit controlling measures that stabilize driving in dependence on data being obtained from the variation of the differential value and evaluated according to criteria indicative of an unstable driving performance.

An embodiment of the invention is illustrated in the accompanying drawings and described in more detail in the following.

In the drawings,

Figure 1 is a vehicle with an ESP control system.

Figure 2 shows the variation of signals of the differential value of the snaking towing vehicle.

Figure 3 shows the signals of a snaking towing vehicle.

Figure 4 is a simplified flow chart showing the control.

Figure 5 is a simplified wiring diagram for calculating the differential value $\Delta\dot{\psi}$.

Before the actual method is referred to, Figure 3 shall be used to schematically explain the signal variation of the oscillation of the yaw rate (dash-dot), of the steering angle (dash-dash), and the differential value of measured yaw rate and model or reference yaw rate in dependence on a slalom maneuver or the slalom-like avoidance of obstacles, respectively. The signal variation a) shows a sinusoidal variation of the yaw rate $\dot{\psi}$ and the differential value $\Delta\dot{\psi}$ of model yaw rate and measured yaw rate without the driver steering. Without a corresponding steering angle variation, the variation of the yaw rate and the differential value of measured yaw rate and model-based yaw rate are almost equal.

Figure 3b) shows the signal variation that is e.g. produced in a slalom maneuver when the oscillation is generated by the steering angle variation alone, where the vehicle can follow the driving performance of the driver illustrated in the vehicle model. In this case, the differential value at issue is zero because no deviation between measured yaw rate and model-based yaw rate is determined. The vehicle follows the steering angle predefined by the driver.

Figure 3c) shows the signal variation in dynamic slalom maneuvers. Herein the oscillation is generated alone by the steering angle variation due to the rapid steering angle changes, i.e. at high steering angle velocities. The sinusoidal variation of the differential value is generally based on the fact that the vehicle can no longer follow the vehicle model. That means, the model yaw rate determined in

the vehicle model is no longer identical with the measured yaw rate because the vehicle is no longer able to instantaneously comply with the dynamic steering angle variations.
Figure 1 shows a vehicle with an ESP control system, brake system, sensor system, and communication provisions. The four wheels have been assigned reference numerals 15, 16, 20, 21. One wheel sensor 22 to 25 is provided at each of the wheels 15, 16, 20, 21. The signals are sent to an electronic control unit 28 determining from the wheel rotational speeds the vehicle speed v by way of predetermined criteria. Further, a yaw rate sensor 26, a transverse acceleration sensor 27, and a steering angle sensor 29 are connected to the component 28. Further, each wheel includes an individually actuatable wheel brake 30 to 33. Said brakes are hydraulically operated and receive pressurized hydraulic fluid by way of hydraulic lines 34 to 37. The braking pressure is adjusted by way of a valve block 38, said valve block being actuated irrespective of the driver by way of electric signals produced in the electronic control unit 28. The driver can introduce braking pressure into the hydraulic lines by way of a master cylinder actuated by a brake pedal. Pressure sensors P used to sense the driver's braking request are provided in the master cylinder or the hydraulic lines, respectively. The electronic control unit is connected to the engine control device by way of an interface (CAN).

It is possible to provide a statement about the respective driving situation and, thus, to realize an activated or deactivated control situation by way of a determination of the entry and exit conditions by means of the ESP control system with brake system, sensor system, and communication provisions that includes the following pieces of equipment:

- Four wheel speed sensors
- pressure sensor (braking pressure in master cylinder p_{main})
- Transverse acceleration sensor (transverse acceleration signal a_{actual}, transverse inclination angle α)
- Yaw rate sensor ($\dot{\Psi}$)
- Steering wheel angle sensor (steering angle δ, steering angle velocity $\dot{\delta}$)
- Individually controllable wheel brakes
- Hydraulic unit (HCU)
- Electronic control unit (ECU).

This renders possible one main component of the method for stabilizing car-trailer combinations, i.e. the detection of driving situations, while the other main component, i.e. the interaction with the braking system, also makes use of the essential components of the driving stability control.

A conventional ESP intervention is used to produce an additional torque by purposeful interventions at the individual brakes of a vehicle, said torque adapting the actually measured yaw angle variation per unit of time (actual yaw rate $\dot{\Psi}_{actual}$) of a vehicle to the yaw angle variation per unit of time (reference or model or nominal yaw rate $\dot{\Psi}_{nominal}$, respectively) influenced by the driver. In this arrangement, the input quantities which result from the track desired by the driver are sent to a vehicle model circuit which, by way of the prior-art single track model or any other driving model, determines a model yaw rate ($\dot{\Psi}_{nominal}$) from these input quantities and from parameters being characteristic of the driving performance of the vehicle, but also from quantities predefined by distinctive features of the ambience. Said model yaw rate is compared to the measured actual yaw rate ($\dot{\Psi}_{actual}$). The difference between the model yaw rate and the actual yaw rate ($\Delta\dot{\Psi}$) is converted by means of a so-called yaw torque

controller into an additional yaw torque M_G which represents the input quantity of a distribution logic.

Distribution logic, in turn, determines the braking pressure to be applied to the individual brakes, possibly in dependence on a braking request of the driver demanding a defined braking pressure at the wheel brakes. The purpose of the braking pressure is to produce an additional torque at the vehicle in addition to the desired brake effect, as the case may be, said torque supporting the driving performance of the vehicle in the direction of the steering request of the driver.

Figure 5 schematically shows that part of the ECU 28 wherein the differential value $\Delta\dot{\psi}$ is calculated. ECU 28 includes a vehicle model 50 for producing a model yaw rate. At least the steering angle and the vehicle speed vRef is sent to the vehicle model 50. Further data, which can be included in the model, are the transverse acceleration, the measured yaw rate and a coefficient of friction determined in a coefficient-of-friction and situation detection unit. The model yaw rate is produced from the input signals in the model. In the determining unit 51, the model yaw rate is compared with the yaw rate sensed by the yaw rate sensor 26, and the differential value is determined from the yaw rate and the model yaw rate. The differential value $\Delta\dot{\psi}$ $/dt$ is weighted by a factor produced in dependence on the model yaw rate change and is filtered in filter 52. The factor $\neq 0$ prevents the spurious detection that has been described with respect to Figure 3c).

Figure 2 exhibits the signal variation of the differential value of a snaking towing vehicle.

As a first component of the detection, the method comprises a module for analyzing the variation of the difference of the

model/actual yaw rate $\Delta\dot{\psi}$. The model detects zero crossings 60, 61 of the differential value between the model yaw rate and the measured yaw rate, said differential value to be taken into account for the analysis, and determines the time between two zero crossings. The oscillation frequency is thereby obtained. A half wave is recognized as valid only if the determined frequency lies within a typical band (roughly 0.5 - 1.5 hertz). Further, a half wave is valid only if the amplitude between two zero crossings has exceeded a defined threshold. The number of the valid half waves is counted. When the number of the valid half waves exceeds a threshold value, the differential value condition for detecting a snaking car-trailer combination is satisfied.

Steering movements of the driver are considered directly in the detection signal by way of monitoring the difference between the model yaw rate and the measured yaw rate. When the driver e.g. carries out a slalom maneuver at a low vehicle speed with a low steering angle velocity, admittedly, the measured yaw rate shows a variation from which a snaking car-trailer combination could be concluded. However, the model yaw rate shows the same variation in the slalom maneuver so that the difference signal is almost zero and a spurious detection is ruled out. Thus, spurious detections caused by slalom maneuvers are thus avoided due to this embodiment of the method. In addition, this method simplifies detecting snaking car-trailer combinations in a curve. During cornering, the yaw rate is given an offset so that the oscillation no longer swings about the zero point but about this offset. This fact renders detection more difficult. If, however, the difference between the model yaw rate and the measured yaw rate (yaw velocity) is used, this offset will be compensated. The detection signal will thus always swing about zero.

Another especially favorable embodiment of the method provides that the deviation between actual yaw rate and model yaw rate is additionally weighted by a factor that is calculated in response to the model yaw rate speed. The quicker the model yaw rate change is, the smaller the factor becomes, which is, however, always >0. Said factor is multiplied by the differential value or differential value signal so that a low differential value is the result in the event of a quick change of the model yaw rate. Thus, detection is only allowed in the presence of extreme oscillations, but is avoided in other cases. It is thereby taken into account that with rapid steering movements the vehicle is no longer able to follow the vehicle model so that the difference between the model yaw rate and the measured yaw rate shows a signal variation that would cause spurious detections.

In another especially favorable embodiment of the method, the number of the demanded half waves depends on the frequency of the oscillation. The more half waves are demanded, the more reliable the detection of spurious detections becomes. With low frequencies, however, it will possibly last too long until an intervention can take place when great numbers of half waves are demanded. It is, therefore, favorable to intervene already at low frequencies when small numbers of half waves prevail, yet to demand more half waves at high frequencies.

In another especially favorable embodiment of the method, the demanded oscillation amplitudes are speed-responsive. Oscillations are more critical at high speeds than at low speeds. Therefore, detection takes place already at low differential value oscillations when the car-trailer

combination runs at high speed, while the threshold is raised at low speeds.

In still another especially favorable embodiment of the method, separate entry and exit thresholds are provided for the differential value amplitudes. An intervention takes place only when the yaw rate exceeds the high threshold. Thereafter, the intervention will only be terminated when values drop below a lower exit threshold. This will ensure that there is a defined intervention and will prevent that the controller is constantly activated and deactivated again.

As a second component of the detection, the method comprises a module for analyzing the transverse acceleration variation. Maximums and minimums of the signal are determined. The frequency can be determined from the distances in time between maximums and minimums. The frequency must roughly correspond to the frequency of the differential value signal. The position of the maximums and minimums of the transverse acceleration signal is compared with the position of the maximums and minimums of the differential value signal. The phase shift between differential value and transverse acceleration can be calculated therefrom. The phase position during driving on rough roadways is different from the phase position during driving with snaking car-trailer combinations. The phase shift is small with snaking car-trailer combinations. This criterion is examined, and the detection of a snaking car-trailer combination is forbidden in the event of a too great phase shift.

In another especially favorable embodiment of the method, spurious control activations are prevented by way of several additional plausibility tests of the transverse signals. The

following signal variations are untypical with snaking car-trailer combinations and, therefore, cause prevention or stop of interventions:

- The frequency of the transverse signals is obviously changing (becomes significantly lower or higher).
- The frequency of the transverse signals lies outside the typical frequency band.
- The amplitude of the transverse signals is significantly decreasing.
- The difference of the maximums and minimums of the transverse signal variations is small.
- The absolute value of the average value of the transverse acceleration is too high (extreme cornering maneuver; snaking car-trailer combinations are not plausible in such maneuvers).

Figure 4 shows a simplified view of the logical processes of the control:

Starting from the yaw rate difference 41 ($\Delta\dot{\psi}$) between the model yaw rate and the measured yaw rate determined in the ESP vehicle model (see e.g. the driving stability control according to Figures 1 and 2 and their description in DE 195 15 056 which shall be part of this application), the differential value 41 is filtered in step 40. This means that the differential value 41 undergoes low-pass filtering so that extreme peaks will not occur. Step 42 comprises the search for half waves in the input signal, which are analyzed by way of two zero crossings, one maximum, a minimum amplitude and a defined initial gradient. It is polled in lozenge 43 whether the half wave was detected. If this is not the case, switch-back to step 42 is made and the search for half waves is

continued. If the half wave was detected by way of the previous criteria, it is checked in terms of its validity in lozenge 44. To this end, the following criteria are polled:

- The maximum of the half wave must exceed a defined value.
- The distance of the zero crossings (half wave length) must be in the significant frequency range.
- The hysteresis band must be left after a defined time.
- Starting with the second wave found:
    - The half wave length must be identical with the previous one.
    - The average value of the transverse acceleration must not be higher than a defined value.
    - The transverse acceleration must have the same sign at the time of the maximum of the half wave.
    - The transverse acceleration must have a half wave of roughly the same duration.
    - The model yaw rate must have the same sign at the time of the maximum of the half wave.
    - The model yaw rate must be smaller than the vehicle yaw rate by a certain amount.

If all of these criteria are satisfied, the half wave is valid, and the half wave counter is incremented in step 45. In the case of a significant amplitude decrease (current amplitude is only X% of the previous amplitude), the counter will not be incremented but maintains its value, what can lead to a later entry into the control. If not all the criteria are satisfied, the half wave counter is reset to zero in step 48.

It is found out in lozenge 46 whether N half waves are detected. This will trigger a deceleration control of the vehicle in step 47.

The criteria allow a control during cornering and even during steering movements of the driver.